# High-Fidelity Micromechanics Model Developed for the Response of Multiphase Materials

A new high-fidelity micromechanics model has been developed under funding from the NASA Glenn Research Center for predicting the response of multiphase materials with arbitrary periodic microstructures (see the figure on the left and refs. 1 and 2). The model's analytical framework is based on the homogenization technique, but the method of solution for the local displacement and stress fields borrows concepts previously employed in constructing the higher order theory for functionally graded materials (ref. 3). The resulting closed-form macroscopic and microscopic constitutive equations, valid for both uniaxial and multiaxial loading of periodic materials with elastic and inelastic constitutive phases, can be incorporated into a structural analysis computer code. Consequently, this model now provides an alternative, accurate method.
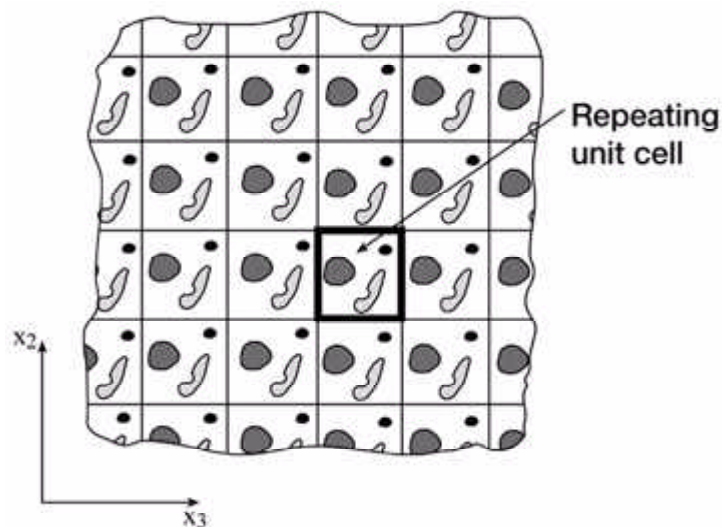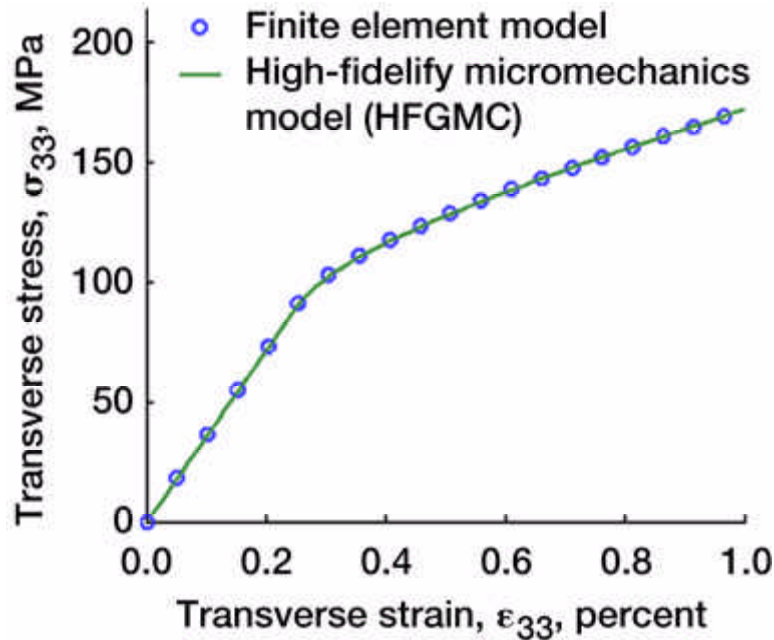
Left: Multiphase material with periodic microstructure. Right: Macroscopic stress-strain response under combined biaxial loading (ref. 2).

Long description Left: Schematic of a multiphased composite that is represented by a periodic arrangement of unit cells containing multiple materials, inclusions, and/or defects; shows repeating unit cell. Right: Transverse tensile stress-strain simulation curves for a 25-vol% fraction graphite/aluminum composite subjected to a biaxial load. Both the finite element and high-fidelity methods give identical results over the entire range of loading.

This new high-fidelity micromechanics model (named HFGMC, High-Fidelity Generalized Method of Cells) now enables the accurate simulation of both averaged (macro) and local (micro) stress and strain fields of heterogeneous materials such as ceramic, metal, and polymeric matrix composites employed in the aerospace, electronic, and biomedical industries. Traditional civil engineering construction materials, such as concrete and filled asphalt, can also be modeled using the developed approach. Prior to this innovation, one could accurately capture both microfields and macrofields only by using the computationally and labor intensive finite-element unit cell approach. An example of the excellent predictive capability of the averaged (or macroscopic) stress-strain response of a 25-vol%-fraction graphite/aluminum composite is shown in the graph on the right. Similarly, the corresponding internal ormicrolevel stress and strain fields are also simulated with very good accuracy, as evidenced in the final figure, where a comparison with finite-element results of the effective plastic strain are shown as well. A user-friendly interface for the model is currently under development to facilitate its use in design-oriented applications, including advanced material development and analysis.
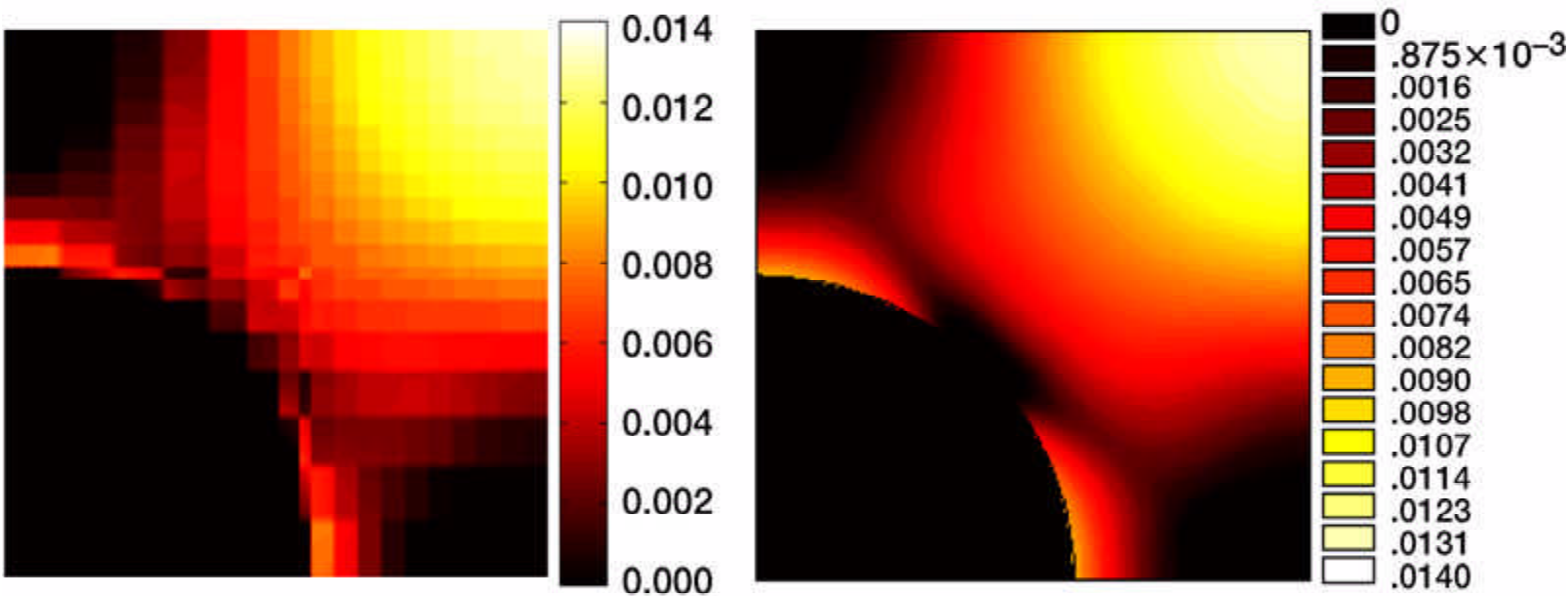
Comparison of the effective plastic strain fields obtained from the high-fidelity model and finite element analysis of a graphite/aluminum composite with 25-vol% fiber content subjected to biaxial loading (see the preceding figure on the left) at the applied strain of 1.0 percent.

Long description: Effective plastic strain contours within both the fiber (graphite) and matrix (aluminum) materials over one quarter of the unit cell, given a graphite/aluminum composite with 25-vol% fiber content subjected to biaxial loading. The microfield quantity (effective plastic strain) shown corresponds to the point in time when the applied transverse macrostrain is equal to 1.0 percent. The leftmost figure shows the results coming from the high-fidelity generalized method of cells approach, whereas the rightmost figure gives the results coming from the finite element method. Comparing the two figures, it is clear that the methods give almost identical results. Note that the highest (indicated by the yellow color) effective plastic strain occurs at the upper right corner of the unit cell, whereas no plastic strain (indicated by the black color) is present in the elastic fibers, as expected.

References

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2. Aboudi, J.; Pindera, M.-J.; and Arnold, S.M.: Higher-Order Theory for Periodic Multiphase Materials With Inelastic Phases. NASA/TM-2002-211469, 2002.

3. Aboudi, J.; Pindera, M.J.; and Arnold, S.M.: Higher-Order Theory for Functionally Graded Materials. CPSOA, Part B--Engineering, vol. 30, no. 8, 1999, pp. 777-832.

Glenn contact: Dr. Steven M. Arnold, 216-433-3334, Steven.M.Arnold@grc.nasa.gov
Authors: Prof. Jacob Aboudi, Prof. Marek-Jerzy Pindera, and Dr. Steven M. Arnold
Headquarters program office: OAT
Programs/Projects: RLV, RAC